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RESEARCH ON CRYPTOSTEADY-FLOW THRUST GENERATORS. (U)

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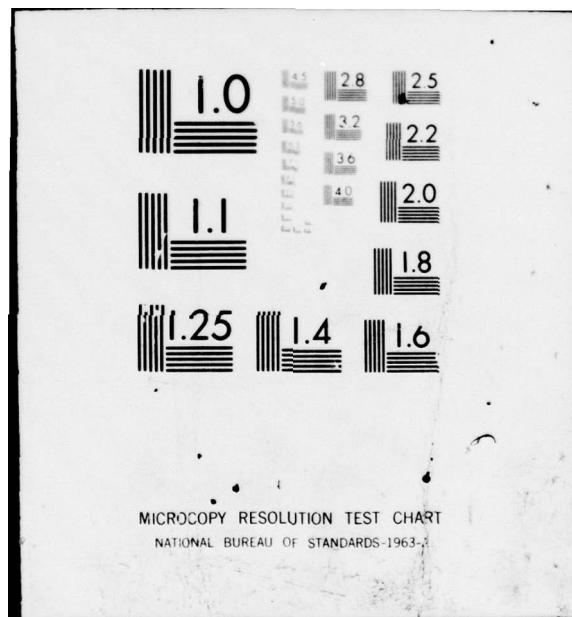
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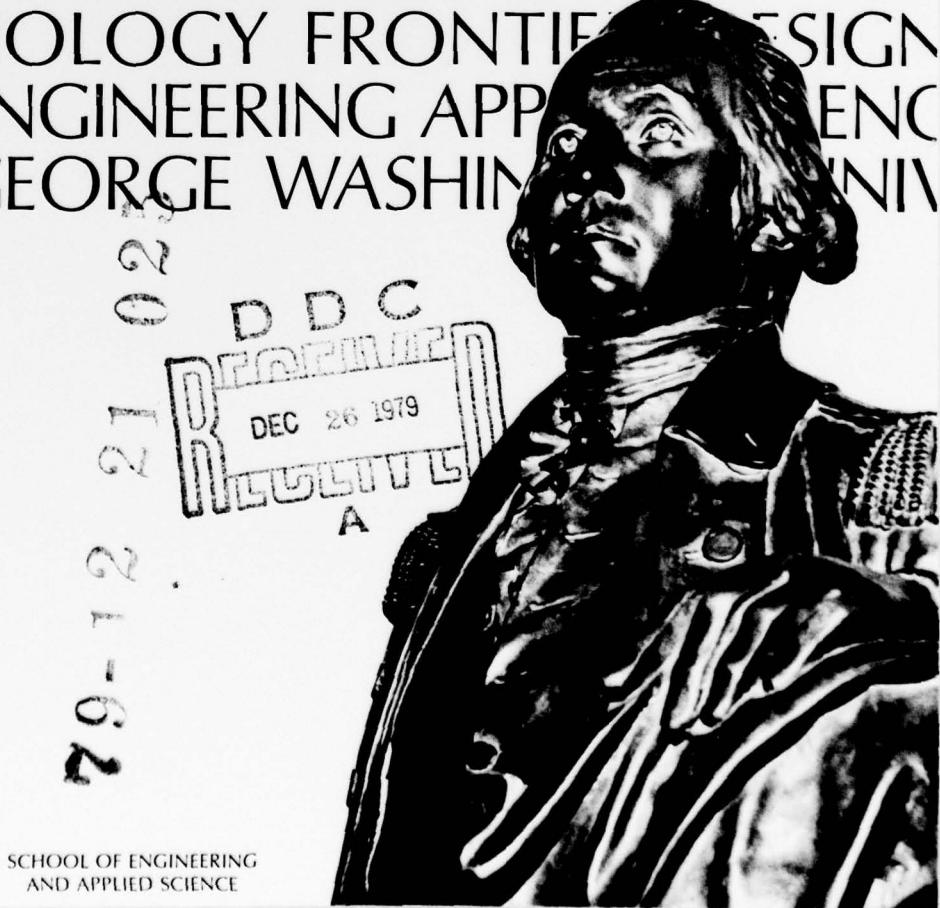
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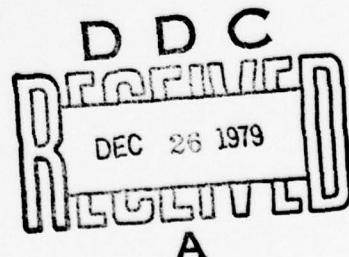
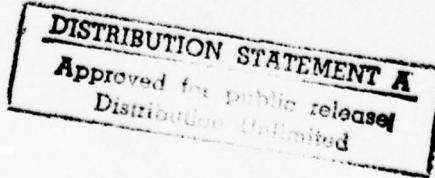
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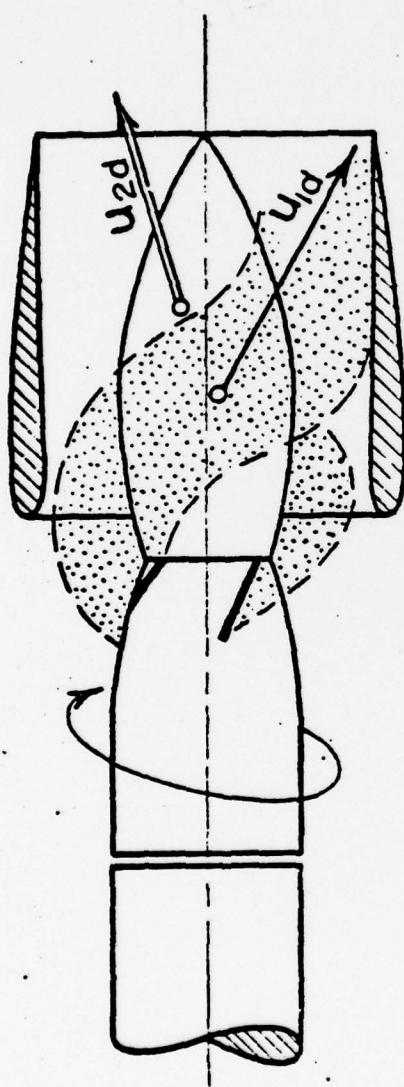
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This report covers the work done under ONR Contract at the George Washington University, during the period from January 1, 1976 to November 30, 1979, on the subject of cryp-
to steady flow thrust augmentation.

The study focussed, from the start, on the "rotary-jet" thrust augmenter, as developed at Rensselaer and tested at MacDonnell-Douglas, Grumman, the Naval Air Propulsion Test Center, and other facilities. In this device (Fig. 1) the primary (or driving) flow is discharged into the interaction space through skewed nozzles on the periphery of a free-spinning rotor, thereby forming the helical rotating patterns that are sometimes referred to as "pseudoblades". The idea here is not to promote mixing (although this may be a side benefit), but rather to generate and utilize an additional mechanism for the transfer of mechanical energy from the primary to the secondary flow. This additional mechanism is "pressure exchange" -- the work of interface pressure forces. Since the pressure exchange component of energy transfer is essentially nondissipative, the performance of the rotary jet can be expected to be better than that of the conventional ejector -- a fact that had already been confirmed experimentally prior to the start of this project.

Work on this program at the George Washington University has been entirely theoretical. The experimental phase of the program was conducted at the U.S. Naval Academy under the

Fig. 1



supervision of Profs. A. A. Pouring and J. F. Sladky, Jr.

The first step in the GWU effort was to develop a generalized performance analysis to cover a whole spectrum of underwater thrust augmenters, from the ejector to the marjet and to the rotary jet, with incompressible, compressible non-condensing, and compressible condensing primary fluids (Refs. 1 and 2). The theory also accounts for the flow nonuniformities that are produced in the glancing collision and mutual deflection of the two flows at the beginning of their interaction, and has yielded useful information. Its main value lies in the fact that it provides a common basis for comparative evaluations of competing thrust augmenters. It reveals, e.g., that the use of a two-phase (air-water) primary could bring about important improvements of performance, and it establishes under what conditions -- and to what extent -- a condensing primary would be better than a noncondensing one (Figs. 2 and 3).

This analysis is, however, still based on the assumption -- also used in previous analyses -- that the penetration of the secondary flow into the spaces between the pseudoblades is completed before the two flows deflect each other to a common orientation in the rotor-fixed frame of reference (Fig. 4). On the basis of this assumption, if the interaction space is not too deep, the flow field can be treated as two-dimensional. This analytical model is, however, likely to be optimistic.

The only alternative approach available at the start of this project was that of Hohenemser's thin-jet-strip theory,

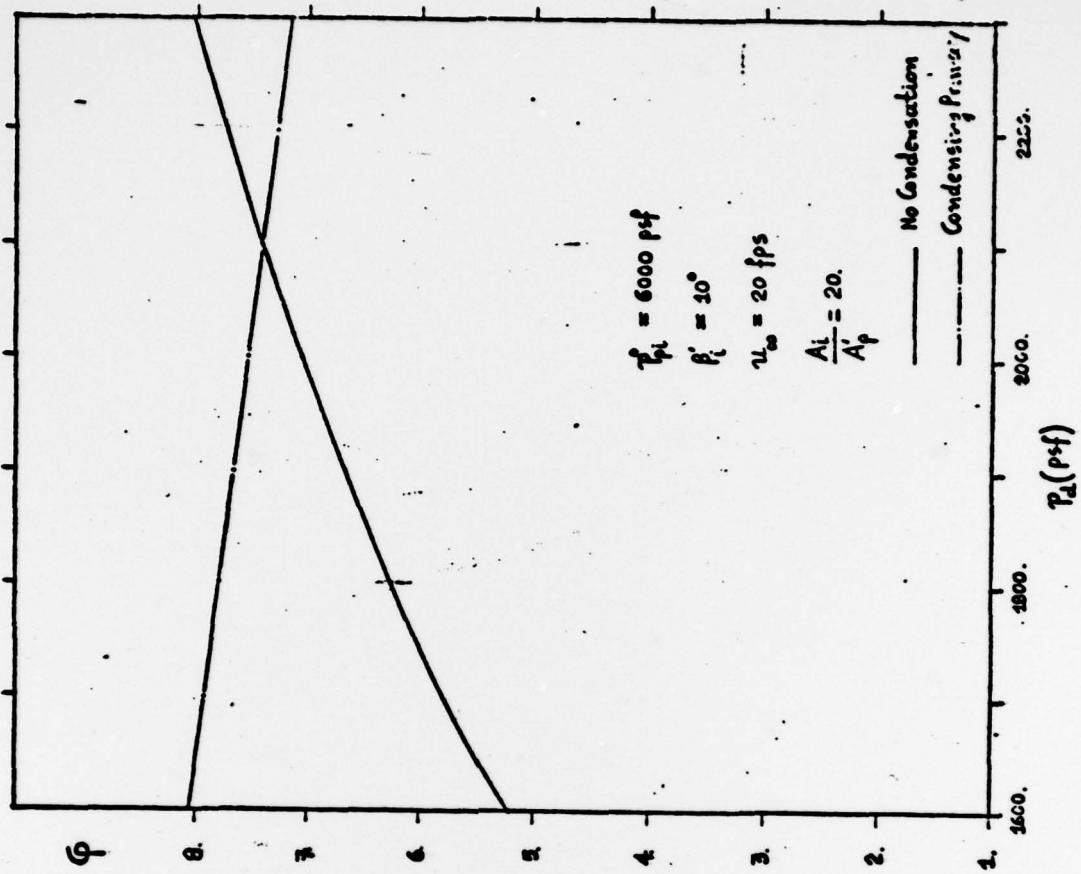


Fig. 3

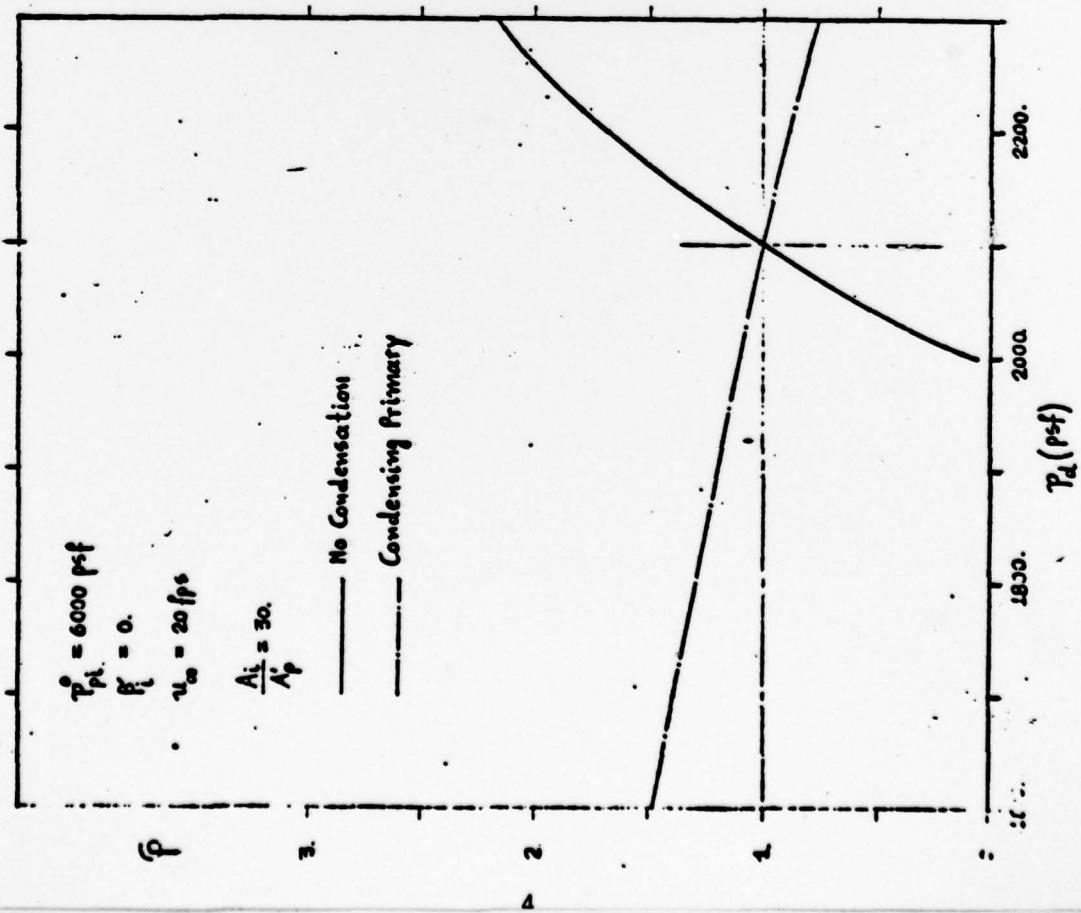
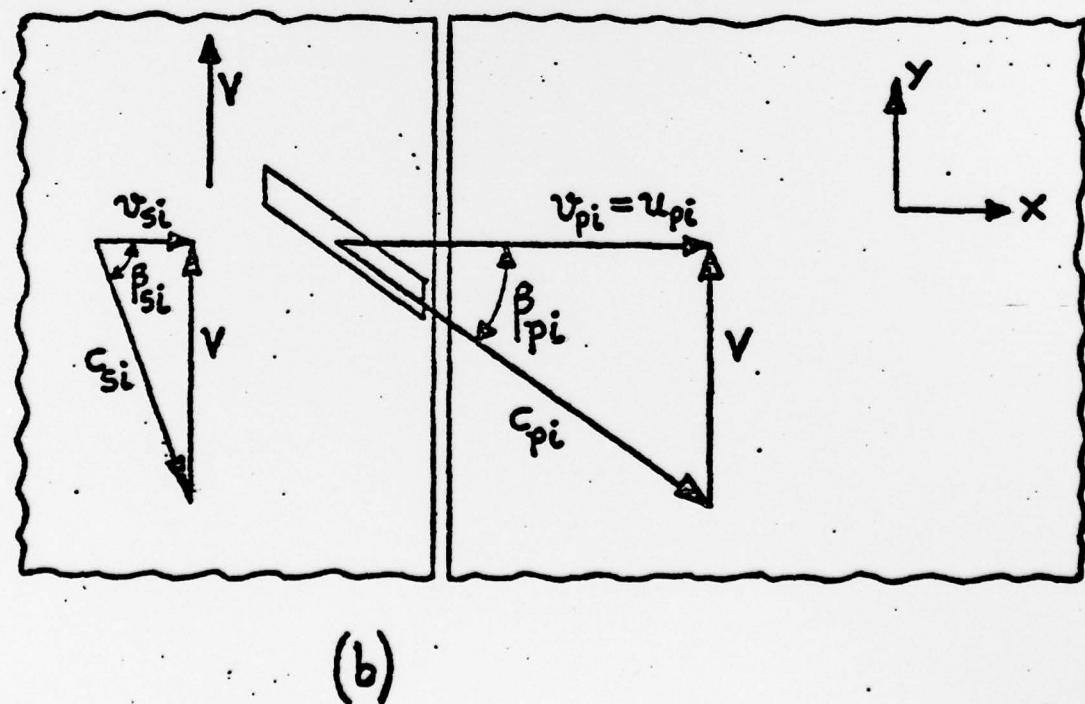
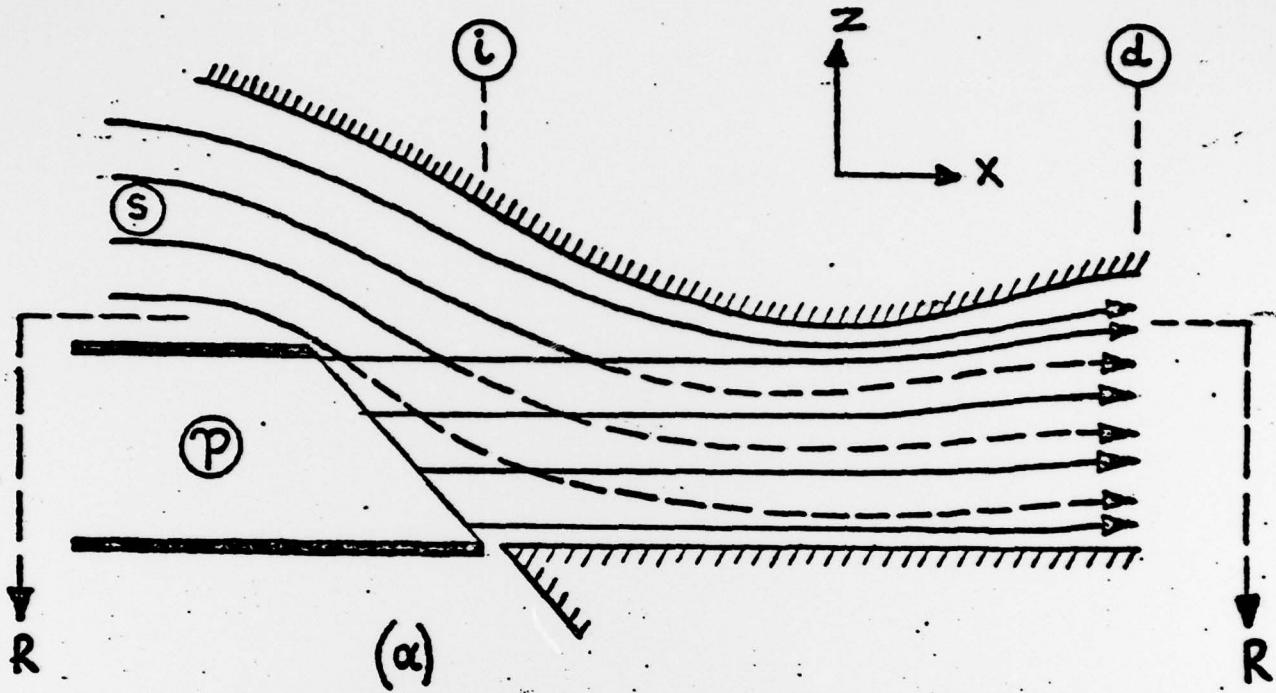


Fig. 2



in which the primary is treated as a very thin jet successively interacting with infinitesimal layers of the secondary flow (Fig. 5). In each of these infinitesimal steps, as the two interacting flows deflect each other to a common orientation, the primary jet, which is finite, undergoes an infinitesimal deflection, and the secondary layer, which is infinitesimal, undergoes a finite deflection. The changes of angular momentum of the two flows in each step must be equal and opposite. The equation expressing this fact yields the distribution of deflections and velocities at the exit from the interaction space, and therefore also the thrust augmentation ratio.

It was felt that a more realistic analytical model would account for the part of the interaction that takes place where the secondary flow enters the space between the pseudoblades. As Fig. 6 shows, different layers in both flows undergo different histories, different deflections, and different exchanges of mechanical energy. Detailed studies of the interaction according to this model (Ref. 3) have provided a wealth of new information. They have revealed, for example, that, contrary to previous results, mixing after the mutual deflection phase is always beneficial if no account is taken of the drag and weight penalties that are associated with the required extension of the shroud (Fig. 7). Actually, beyond a certain spin angle, the benefit that can be derived from mixing becomes too small to offset these penalties.

The same analysis has also yielded some information on the progressive cross-sectional deformation of the pseudoblade

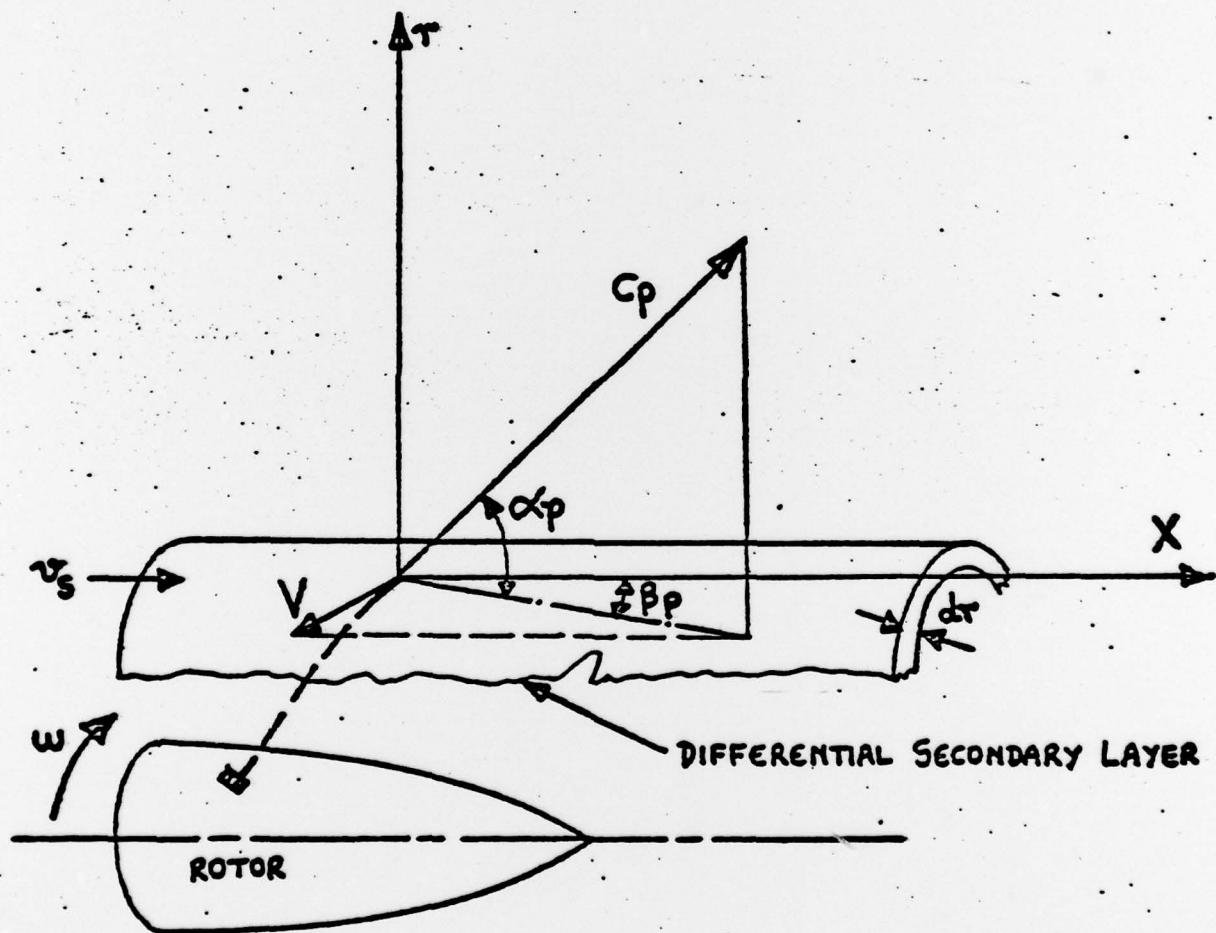
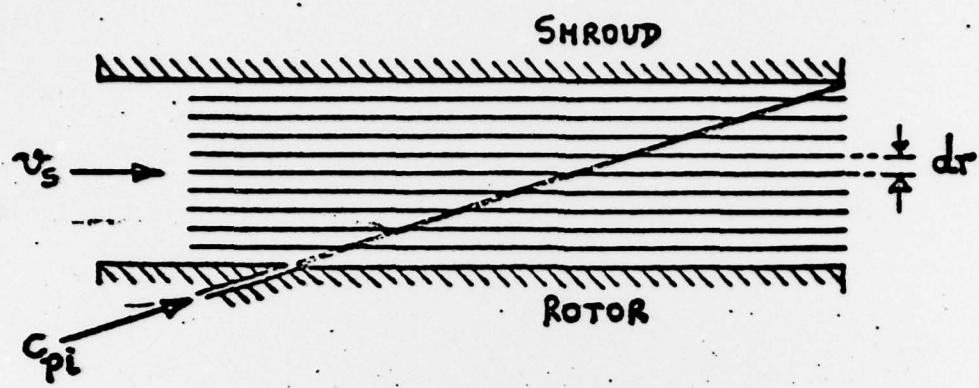
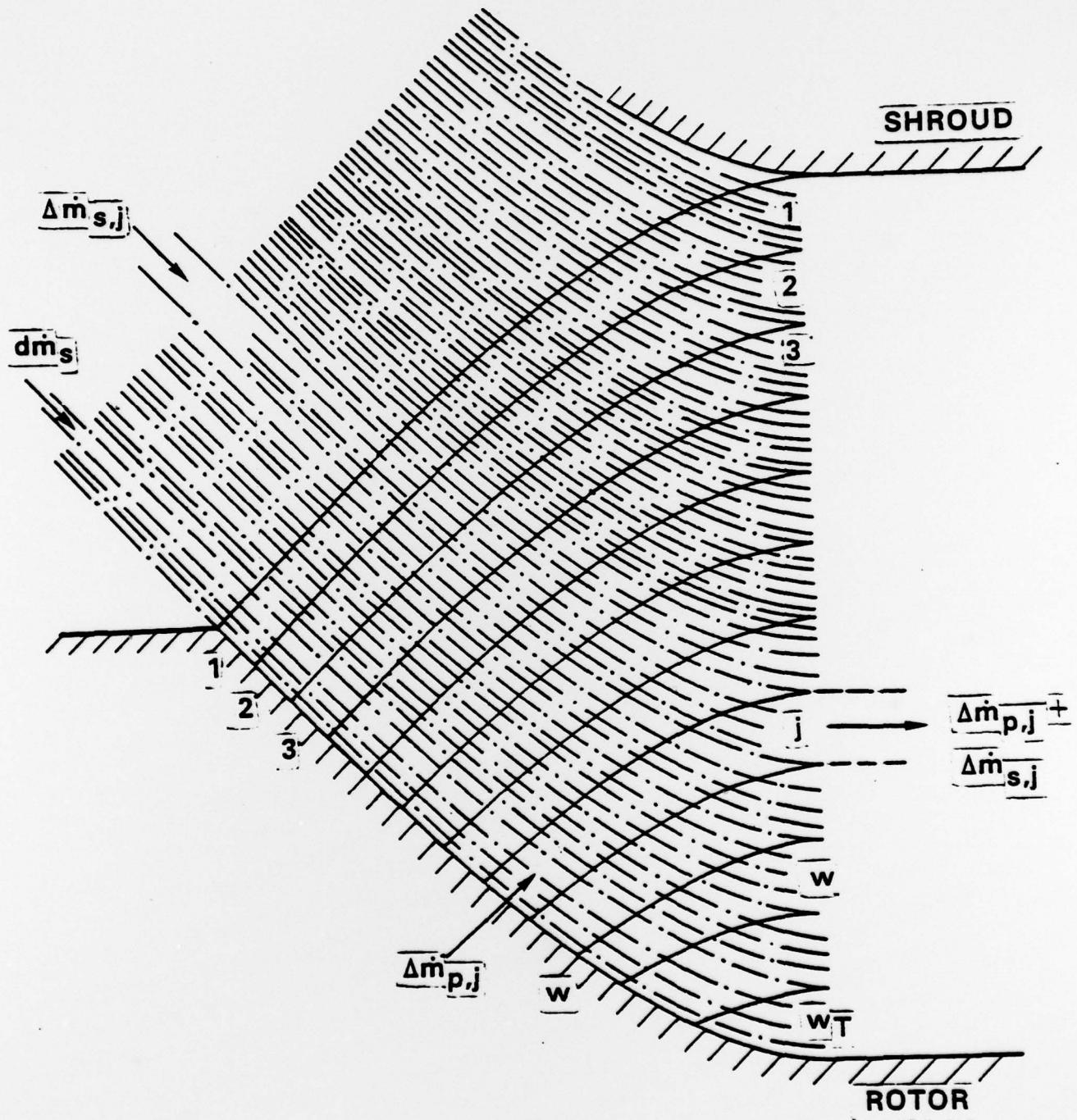
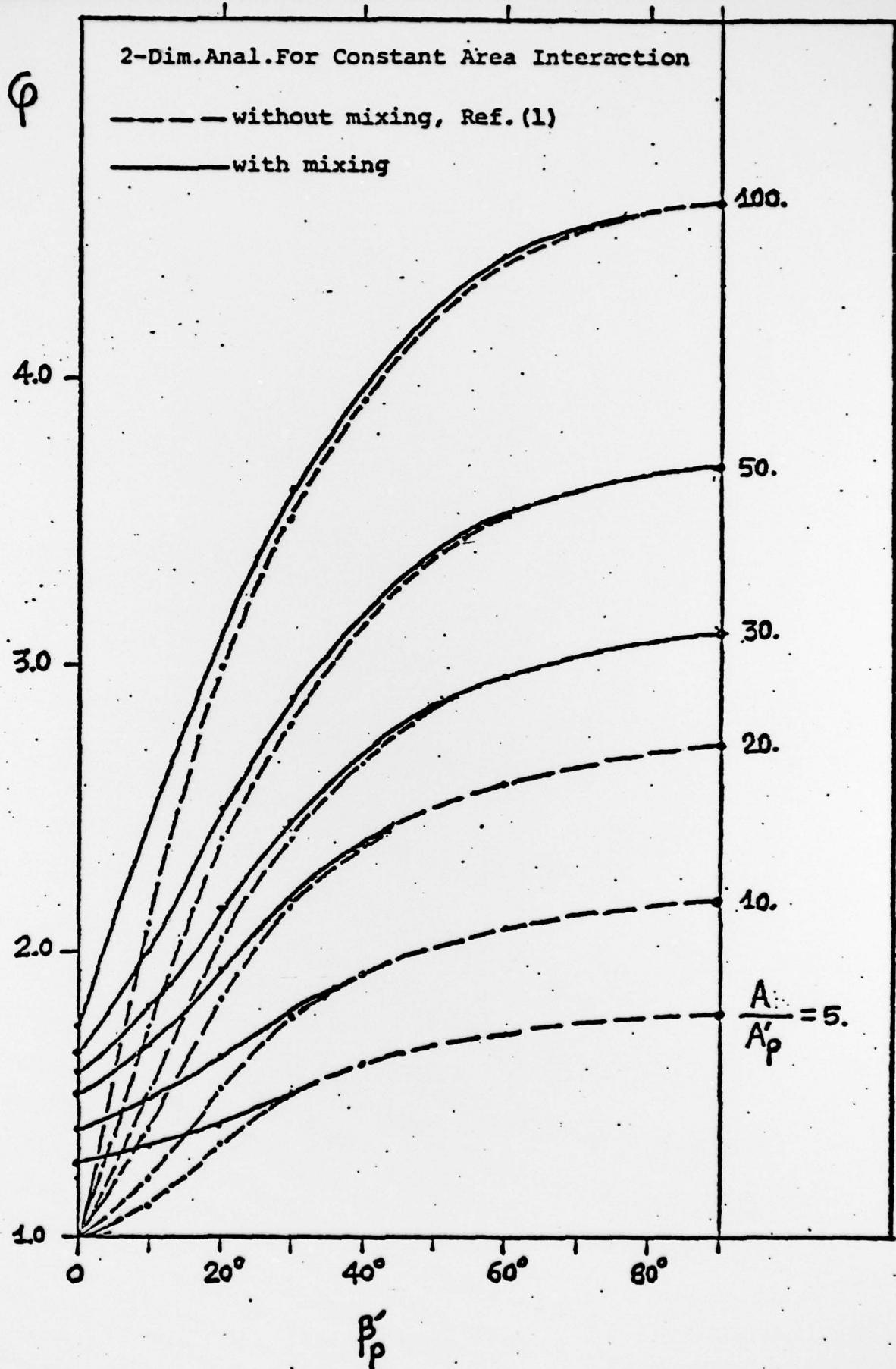


Fig. 5





and on the effect of rotor orifice shape on rotary-jet performance.

Fig. 8 shows a comparison of the performance predictions of the above-mentioned theories.

Fig. 9 shows that what happens when any appreciable mixing is allowed to take place during the deflection phase. The effect is in this case always an adverse one, as one would expect, since any energy that is transferred through mixing during the deflection phase is energy that could have been transferred more efficiently by pressure exchange.

In a separate study (Ref. 4), a "black box" approach was used to show that the superiority of the rotary jet over the ejector can be explained as an effect of pressure exchange alone, quite apart from whatever benefit may be derived from the enhancement of mixing. The same paper also considered the effect of secondary-to-primary density ratio and showed that the effect of increasing this ratio may be beneficial or adverse, depending on the magnitude of a parameter called "pressure exchange amplitude", which is a measure of the vigor of the collision. This study was continued in Refs. 5 and 6, with the interesting result that, whereas in the ejector the best density ratio is 1.0, in the rotary jet, beyond a relatively low spin angle, the effect of an increase of density ratio is always beneficial (Fig. 10).

Attention was given to means for delaying or preventing the occurrence of flow separation over the surface of the centerbody boattail. The adverse pressure gradient that one would normally expect over such a surface is likely to be

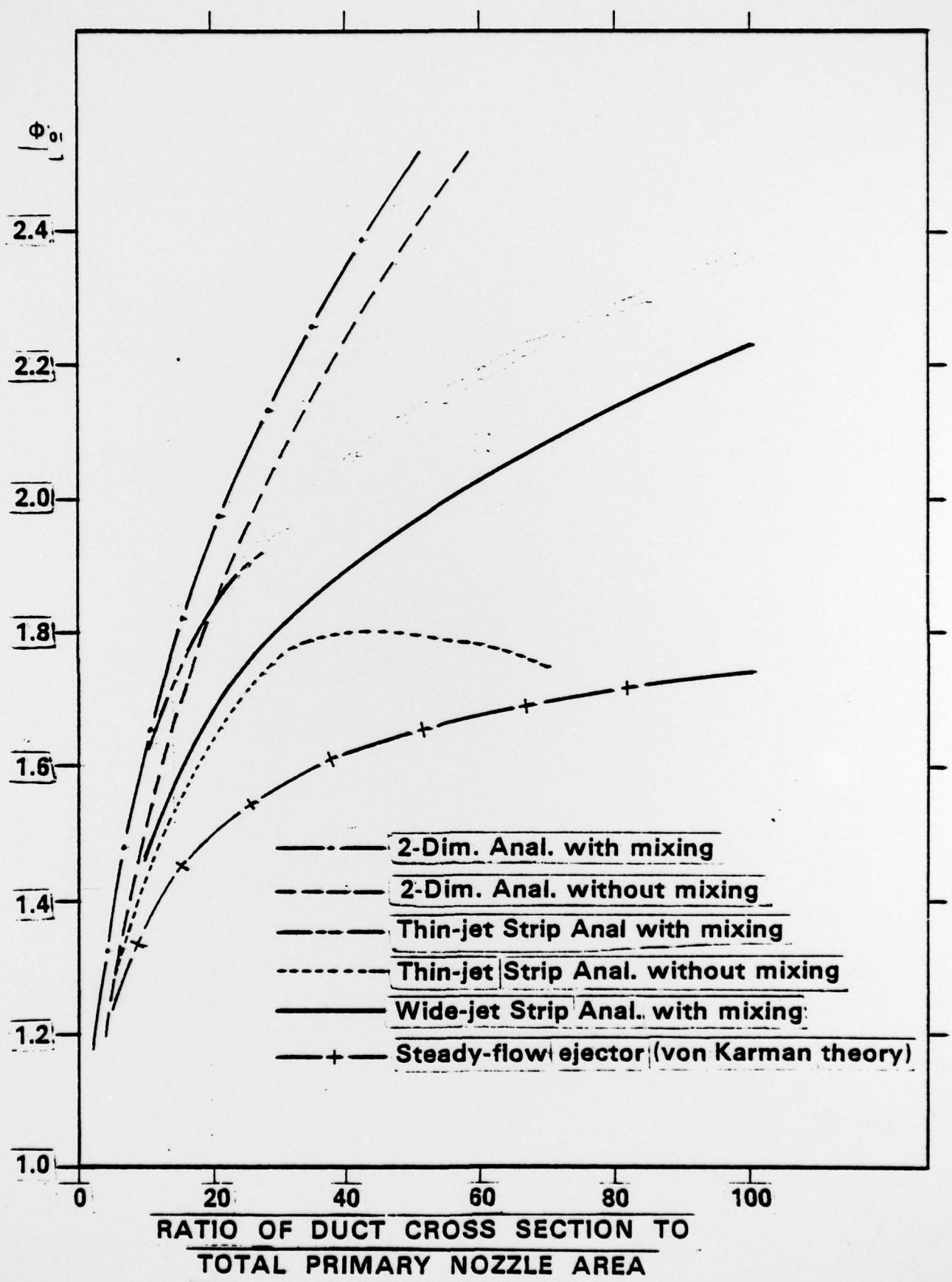


Fig. 8

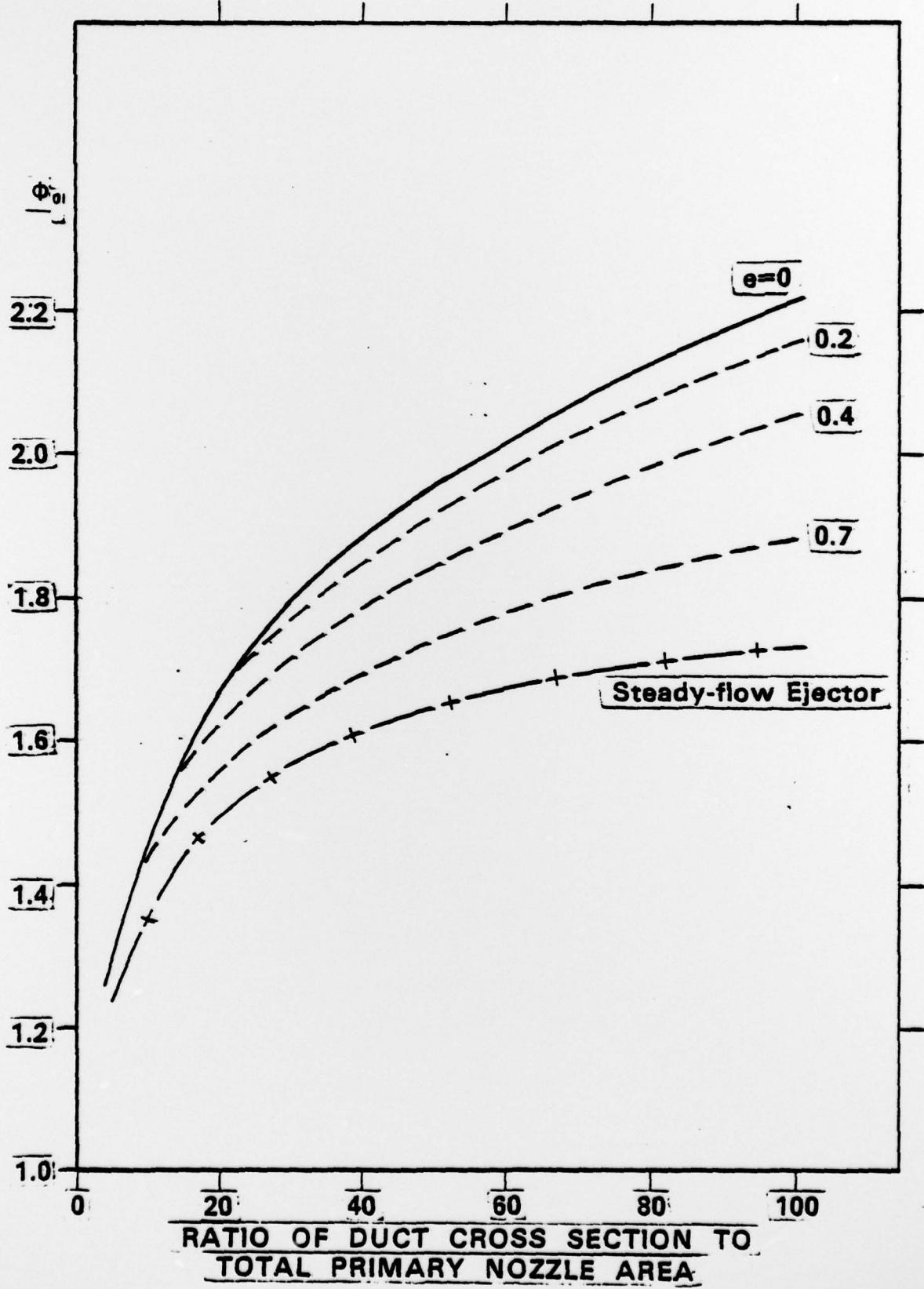
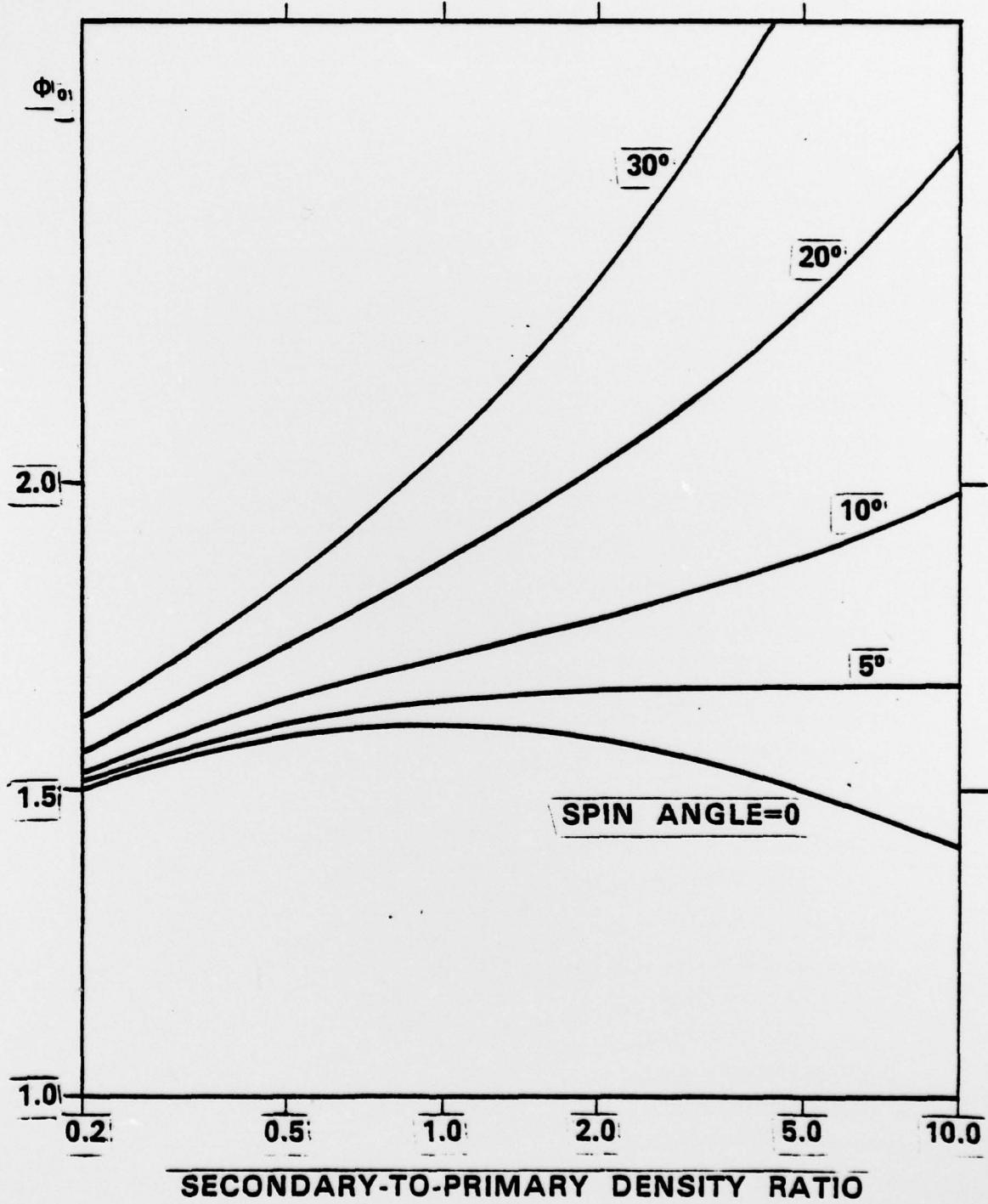


Fig. 9



aggravated, in the case of the rotary jet, by the pressure modifications which are generated by the action of the pseudoblades. Thus, flow separation can be expected to produce a double loss of performance -- through an increase of pressure drag of the rotor and through a loss of pumping effectiveness of the pseudoblades. Fig. 11 shows a possible remedy to this difficulty -- the "core flow" arrangement, whereby a portion of the primary flow is diverted from the entrance to the rotor nozzles and is discharged instead through a central passage. This arrangement would serve the double purpose of eliminating the most critical portion of the afterbody surface and of alleviating the adverse pressure gradient, through the entrainment action of the central jet acting like the primary of an ejector. It is also expected that a further improvement of performance could be obtained by pumping air into the water flow in the central passage. The core-flow arrangement is discussed and analyzed in Refs. 7,8 and 9.

As has been mentioned earlier in this report, rotary-jet performance is adversely affected by the flow distortions which accompany the interpenetration of the two interacting flows and by any mixing that may occur during their mutual deflection. Both effects may be alleviated through the use of rotor-nozzle extensions, or "hoods", as illustrated in Fig. 12, where the upper portion shows the "standard" configuration and the lower portion a hooded one. The purpose of the hoods is to shield the two flows from one another during part or all of the interpenetration phase, thus preventing or reducing the entrainment during deflection and bringing the

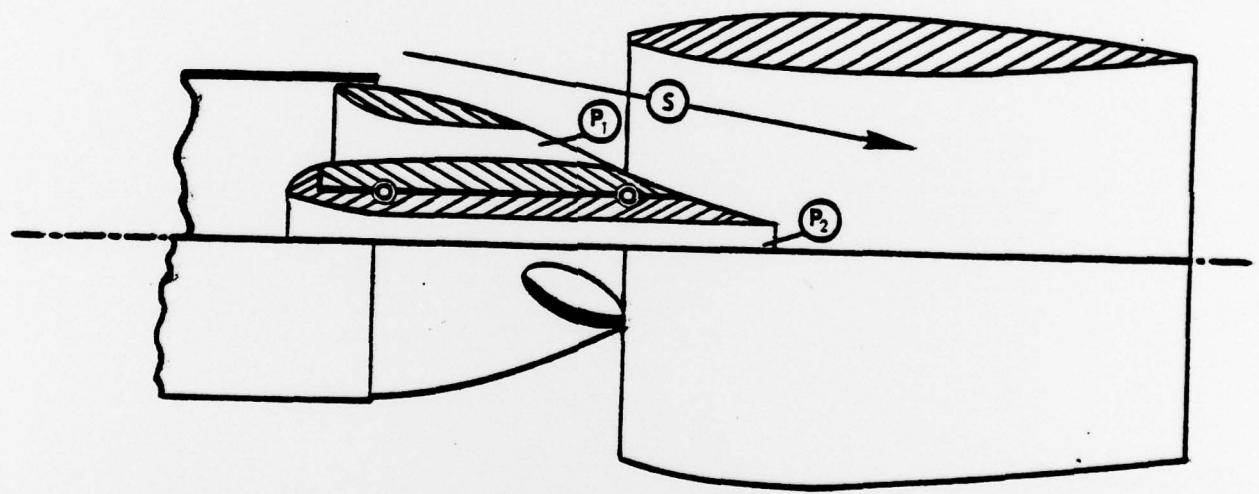


Fig. 11

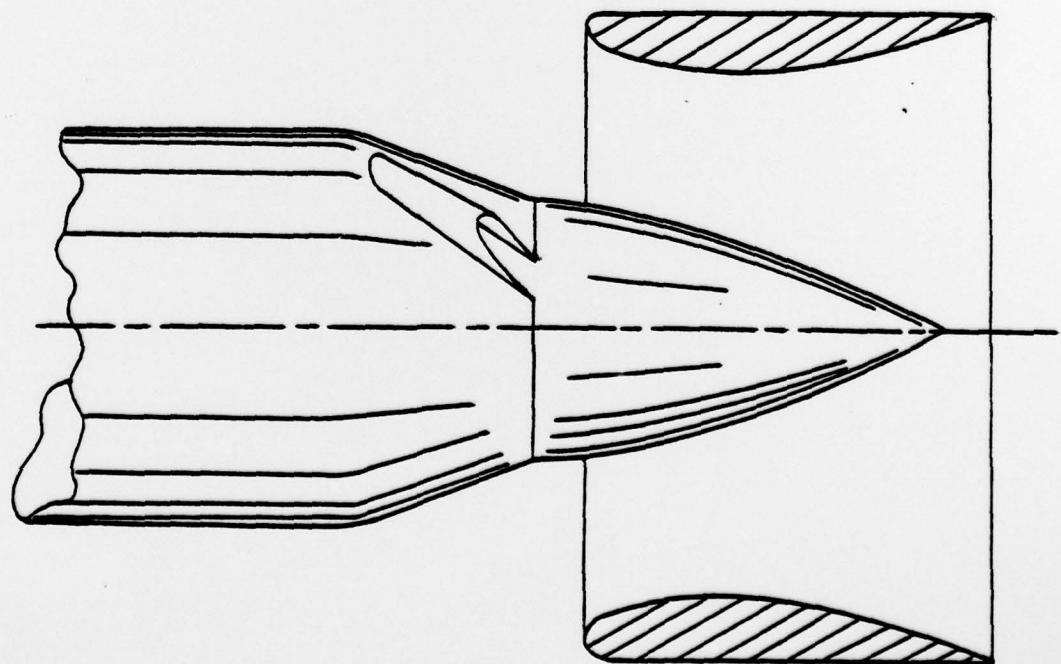
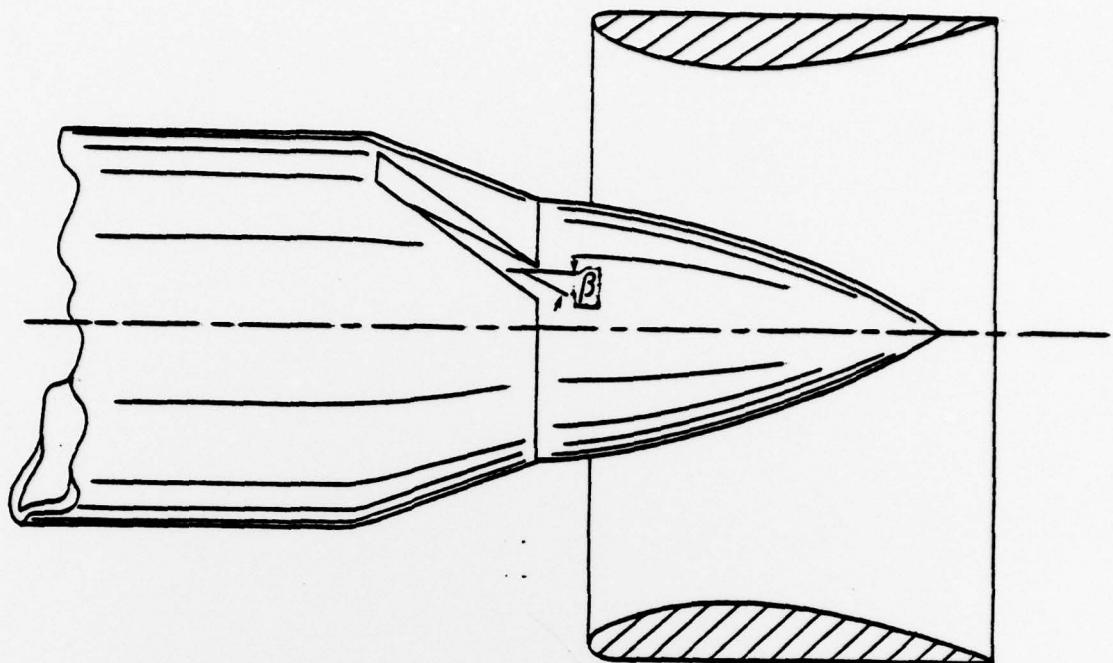


Fig. 12

interaction, downstream of the hood exit, closer to the two-dimensional ideal. These benefits are, however, diminished (and may even be offset) by accompanying penalties -- lower nozzle efficiencies, probable flow separation over the hood surface, and most importantly, reduced rotor speeds.

A method is developed in Ref. 10 for an approximate determination of the "optimum" hood configuration, when such an optimum exists. The results indicate that, for example, in the case of a rotary jet with a spin angle of 20° and an area ratio (shroud exit to primary discharge) of 20, hoods extending about half-way to the shroud could increase the static thrust augmentation ratio by as much as 10 to 12.5 percent over that of the unhooded device, all else being equal. Longer hoods would reduce the thrust augmentation.

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